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sensor, temperature, pressure, emission, diagnostic signal, efficiency

Marcin RYCHTER[1]

CONDITION IN CI ENGINE'S EXHAUST PIPE IN LIGHT OF APPLICATION NO_X SENSOR TO DETERMINE OF CATALYTIC CONVERTER EFFICIENCY

The paper presents main method of monitoring catalytically converter in CI engines. There is characterizing of methods and sensors. In this paper presents modified test bed witch used to testes of exhaust pipe in light of determination possibility of application measurement probe to determine of NO_X concentration. Those investigation could help to evaluate of possibility catalytically converter monitoring within the framework on board diagnostic systems.

WARUNKI PANUJĄCE W UKŁADZIE WYLOTOWYM SILNIKA O ZS W ŚWIETLE ZASTOSOWANIA CZUJNIKÓW NO_X W CELU OKREŚLANIA SPRAWNOŚCI REAKOTORA KATALITYCZNEGO

W artykule przedstawiono wybrane sposoby monitorowania reaktora katalitycznego w silnikach o zapłonie samoczynnym. Scharakteryzowano metody te oraz opisano elementy wykonawcze. Przedstawiono zmodyfikowane stanowisko badawcze, na którym przeprowadzono badania układu wydechowego w celu określenia możliwości zastosowania sond pomiarowych określających stężenia NO_x. Badania te zostały przeprowadzone w celu rozpoznania możliwości monitorowania reaktora katalitycznego w ramach pokładowych systemów diagnostycznych.

1. INTRODUCTION

The OBD system (On Board Diagnostic system; known in the United States as the OBD II system and in Europe as the EOBD one) is a set of diagnostic tests and calculation and decisive procedures which are performed in a real time and are intended as a measure for evaluation of the emission efficiency and the efficiency of elements responsible for the passive and active safety of a vehicle. The OBD system is an integral part of the vehicle connected with the engine control system. Nowadays the investigation on the on board diagnostic systems in their different applications is one of the basic problems that the OBD method is concerned with.

In order to satisfy such postulates the realization of the implemented diagnostic procedures during the real operation of vehicles and in the possible shortest time is

[1]Motor Transport Institute, 80 Jagiellońska St., 03-301 Warsaw, Poland, e-mail: rychter@poczta.fm; phone: +48-22-814-12-35; fax: +48-22-811-09-06.

necessary. Thus the evaluation of the operating efficiency OBDE (On Board Diagnostic Efficiency) of the OBD system is also necessary [1, 2].

2. MONITORING OF AFTERTREATMENT SYSTEMS

The carbon dioxide and hydrocarbons emission from the modern self-ignition engines reaches the values near the ones being recorded for the spark ignition engines equipped with the three-function catalyst. Further reduction of the toxic substances from the engines of this type does not present any significant problems. However, the problem is how to limit the nitrogen oxides and particulate matter emission. The compression ignition engines CI are equipped with the exhaust gas catalyst of Oxicat (*Oxidation Catalyst*) and the $DeNO_x$ types and with the particulate matter filter. It happens that the $DeNO_x$ catalyst becomes gradually poisoned by sulphur which is contained in fuel whereas the filter is being filled up with the particulate matter and gets plugged. For ensuring the effective operation of these units their efficiency must be kept under constant monitoring so that it could be possible to start the regeneration procedure immediately, if needed.

The methods developed for the catalyst diagnosis can be divided into three groups [4]:

- methods using the measurement of the exhaust gas temperature,
- methods using the oxygen concentration sensors (quantitative detection of the emitted heat),
- methods using the toxic substance concentration sensors (direct detection of the catalyst operation).

The arrangement of the individual elements of the diagnostic systems belonging to the groups discussed above is presented in fig. 1.

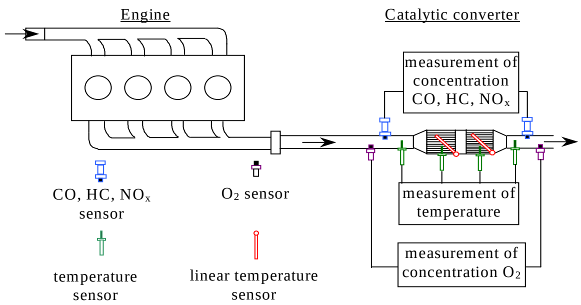

Fig. 1. Diagram of location of on board diagnostic elements in exhaust pipe [4]

The paper [5] presents some opinion that the use of the HC conventional sensors for monitoring the catalyst is unreasonable as the signal value is not satisfactory sensitive to the catalyst efficiency (especially in case of its high temperature operation). However, in accordance with [6], the use of the CO sensors with their simple signal processing algorithm seems to be reasonable when used for the catalyst efficiency evaluation.

The NO_x sensors are more and more often installed in the on board diagnostic systems OBD II/EOBD. The measurement of concentration of CO, HC and NO_x in exhaust gas presents such an exemplary solution. The analyser discussed below performs the simultaneous measurements of concentration of hydrocarbons, carbon oxides and nitrogen oxides. The first valve collects exhaust gas at the catalyst input, the second one collects it at the catalyst output. However, the third valve is used for taking the samples of exhaust gas that have already flown in through the first and second valves and for delivering them to the analyser. The measurement of content of the toxic compounds in exhaust gas makes possible to determine the state of the catalyst.

The amount of NO_x emitted from the engine is conditioned by many factors, starting from the environmental conditions (humidity, ambient temperature and pressure), through the composition and type of fuel and ending on the engine state**.** Up to now all undertaken actions, both to develop any mathematical description of the NO_x emission from the compression ignition engines and to determine the amount of NO_x emission during the control survey of the engine, failed.

In case of the exhaust gas emission from the compression ignition engines the amount of molecular oxygen is about 20 per cent. This situation calls for a solution which could radically extend the range of the oxygen concentration measurement. The solution presented in the paper consists in completing the Nerst's classical cell with an electronic segment which forces an outflow of the oxygen ions. The reference electrode of the Nerst's cell is located in the atmosphere of air. The individual constituents of exhaust gas diffuse through the diffusion barrier into the space in which some state of the thermodynamic balance is attained. The voltage connected to the porous electrodes, which are formed directly on the electrolyte, forces some cathode-to- anode flow of the oxygen ions. The flow of such a type is called "an oxygen pump" [6, 8, 9].

The flow of ions in such "a pump" is proportional to the difference of the oxygen concentrations existing on both sides of the pump. The task for this electronic control unit is to set such a value of the pump flow that the exhaust gas composition in the diffusion space corresponds to the stoichiometric fuel-oxygen mixture. The increase of the applied voltage (for the specified temperature, electrolyte type and electrode distance) intensifies the current in the cell to some value limited by the oxygen concentration.

A method of the nitrogen oxides measurement using the zirconium dioxide-based sensor was developed in the nineties years of the last century. The measuring device consists of a sensor and a recording unit. Exhaust gas gets into the sensor (fig. 5) where in turn in its two diffusion chambers the exhaust gas oxygen content is being removed. The chambers are preheated and coated by zirconium dioxide-based electrodes. The gas, in which 0.01 ppm of O_2 is being left, gets into the measuring chamber where the measuring electrode made of rhodium is placed [10, 11].

The scheme of the operation principle of the NO_x sensor is presented in fig. 2. This sensor is based on six layers of zirconium dioxide. A space for measuring the exhaust gas concentration is on the second layer, the reference space with an access to the air is on the fourth layer whereas the space with an internal heater installed for controlling the temperature is provided between the fourth layer and the sixth one [6, 9, 10, 11, 12, 13].

The operation principle of the NO_x sensor is presented in fig. 6. Exhaust gas entering from the left side comes through the space (1) in which the voltage to be applied is properly selected for the first thin layer made in ZrO_2 (operating as a pump which removes the exhaust gas molecular oxygen O_2 content and reduces NO_2 to N_2. The performance of the oxygen pump is controlled in order to maintain the concentration of O_2 in the space (1) before using the reference electrode to prevent the NO decomposition).Then the exhaust gas passes from the space (1) to the space (2) and NO is transported in an electrolytic way from the third thin layer of ZrO_2 in a form of electrolyte for measuring a current of flow. Thereby from NO remains only O_2 which is subject to the electrolysis in the space (2) and a current of flow is an equivalent of the NO amount.

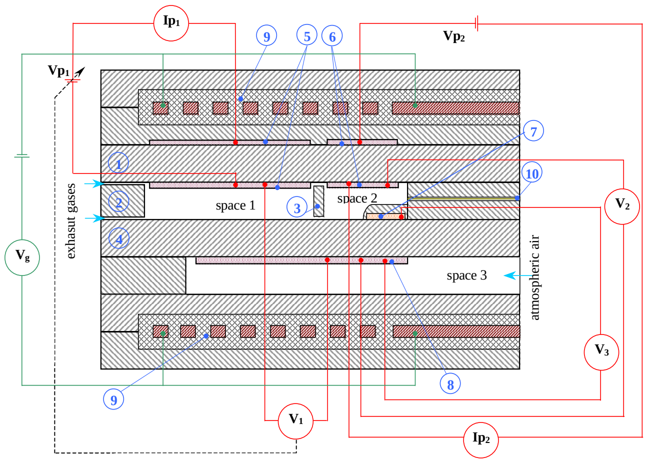

Fig. 2. Operation principle of NO_x sensor: 1 – ionic condacter made (YSZ), 2, 3 – diffusivity of ceramic separator, 4 – ionic condacter (YSZ), 5 – platinum elecoredes, 6 – platinum eleocrode, 7 – platinum-rodium electrode, 8 – platinum elecorede 9 – heaer, 10 – pressure valve [6, 9, 10, 11, 12, 13]

A correct operation of a sensor (its repeatability) depends on [6]: a plate thickness, the area of electrodes, an electrode porosity, a diffusion insert porosity, the area of platinic electrodes located in area on a plate, a diffusion insert porosity and a plate thickness**.**

The Pd-Ag and Pd-Ni alloys usually used in the laboratory studies cannot be used in normal engine operation conditions due to the presence of sulphur in the atmosphere and some susceptibility of their surfaces to degradation. At the normal operation of the compression ignition engine the adsorbed sulphur does not only delay the action of the catalyst bed during a cold start and idle running but also affects the indications of the sensors from these engine operation stages.

Metals used in the NO_x sensors can be ranked in relation to their highest susceptibility to the sulphur corrosion in a following way: Ag > Pd = Ru > Rh = Pt.

3. ANALYSES OF TEMPERATUR DISSOLUTION IN EXHASUT PIPE

The temperature is a basic parameter affecting the ability of generating voltage signals by the sensors produced in the „*sensor to sensor*" technology. Owing to the design of sensors and the constructional materials used for the execution of electrodes in the individual areas, as shown in papers [6, 14], it was necessary to provide an additional reheating to reach the temperatures which enable starting the oxygen pumps. Taking into consideration the operating parameters of the engine examined on the engine test bed the exhaust gas temperatures during the realization of the ESC test could reach the range in which generating the diagnostic signals by the sensors was possible. Overheating the measuring probe of a sensor caused by too high temperatures of exhaust gas while supplying a system of heaters with an external voltage can result in a degradation of electrodes. Therefore the developed laboratory system requires a manual selection of the voltage for supplying a sensor in a way eliminating a risk of exceeding the threshold voltage value for given engine operating conditions. To complete the gathered knowledge on the possibilities of delivering the supply voltage depending on the temperature in the exhaust engine system an analysis of the temperature distribution was carried out in the measuring points of the exhaust system, provided for the NO_x sensors (fig. 3 – 4) [6].

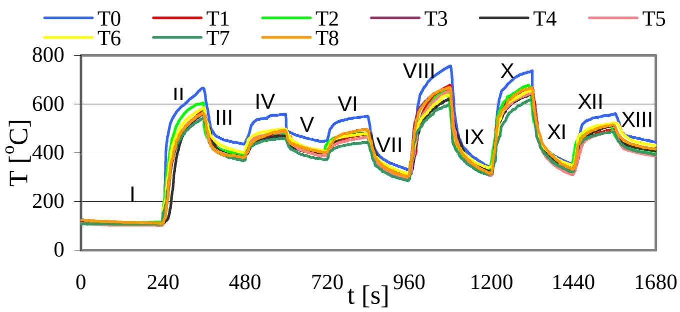

Fig. 3. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine without catalytically converter during realization ESC test [6]

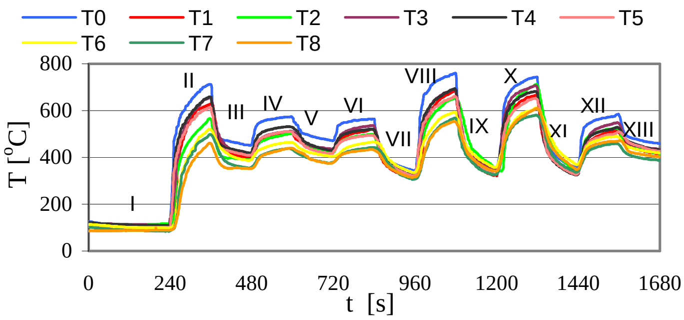

Fig. 4. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine with 200 cpsi catalytically converter during realization ESC test [6]

The performed analysis indicates that with regard to the exhaust gas temperatures the phases II, VIII and X are most critical. It concerns both temperatures measured without and with the catalyst provided. In case of phase II the highest temperature of 710°C was reached at the T0 point of the exhaust system equipped with a catalyst with a carrier of 200 cpsi density.

In case of phases VIII and X the exhaust gas temperature were reaching the values ranging from 737°C to 759°C. These are temperatures at which the sensors, owing to their design and constructional materials for electrodes, are able to generate voltage signals without necessity of reheating. For all other test phases the highest temperatures were reached at the T0 point and the recorded temperatures were not exceeding the value of 600^{o}C.

This analysis indicates that in case of phases VIII and X, during a realization of the engine test bed examinations, the applied sensors will be most sensitive to the controlled supply voltage value. The obtained temperature distribution suggests that for these phases the sensor reactions should be fastest as the optimum sensor temperatures can be reached without necessity of reheating. However, the above applies to the sensor installed at T0.

4. ANALYSES OF PRESSURE DISSOLUTION IN EXHAUST PIPE

The rate of chemical reactions is a function of the reactive exhaust gas components, exhaust gas temperature, type of the applied catalyst and pressure. For reactions proceeding in a gaseous phase the concentrations and pressures are interdependent. However, the pressure can independently affect the reaction rate values, thereby the response times of the sensor in the considered system. In order to find the importance of these variables the experiments should be carry out in a way which makes possible a simultaneous change of the smallest number of parameters. It is impossible to perform such experiments in case of examination being realized under the engine test bed conditions. For this reason the importance of pressure is limited to its effect on the sensor response time with regard to the exchange of exhaust gas present in the sensor's probe.

The pressure in the exhaust system affects the intensity of the gas exchange in a sensor by affecting the pressure present in a measuring probe, as shown in papers [6, 14]. When an increase in pressure in a measuring area is faster the speed of the gas exchange in the individual regions of the NO_x increases and thereby a frequency of the voltage signals should be greater.

With reference to the classic catalyst the engine exhaust system pressure results in a number of the molecules adsorbed within a catalytic layer. Regarding it to the sensor conditions a number of the collisions of oxygen molecules with the electrode *pt* should be also higher what can directly result in the sensor response time value.

In the phase i of the test, in which the engine was operating at idling speed, the average overpressure in the exhaust system without the catalyst was of $0{,}03 \cdot 10^{-4}$ pa (fig. 5). In case of the exhaust system equipped with the catalysts with the 200 cpsi carriers such same overpressure values of $0{,}03 \cdot 10^{-4}$ pa were recorded. From the considered research point of view such values do not allow to get information necessary for the realisation of the next assumed examination. Analysing a distribution of pressure in the exhaust system without the catalyst it can be found that for all phases of the test the pressure differences between the p0–p5 points are small (fig. 5).

In points p6–p8 which are distant from the point p5 by 60 cm the pressure values are also similar. In every phase, depending on the overpressure values, the measuring points can be separated into two groups of points p0–p5 and p6–p8. In points p6–p8 the overpressure values in every phase are smaller what results from their greater distance from the exhaust collector. The differences in the overpressure values measured in the measuring points of the individual groups can be explained by the pressure fluctuation in the engine exhaust system and an indication error of the applied pressure measuring sensors (fig. 6).

As the distance from the exhaust collector increases the pressure value decreases. In case of measuring points before (p0), in (p1 – p4) and just after the catalysts (p5), the differences in the overpressure values are caused by the exhaust gas flow resistance in the individual catalytic blocks. For every test phase in points distant from the catalyst (p6 – p8) the pressure values are much lower and continue their falling tendency depending on the distance in relation to the exhaust collector.

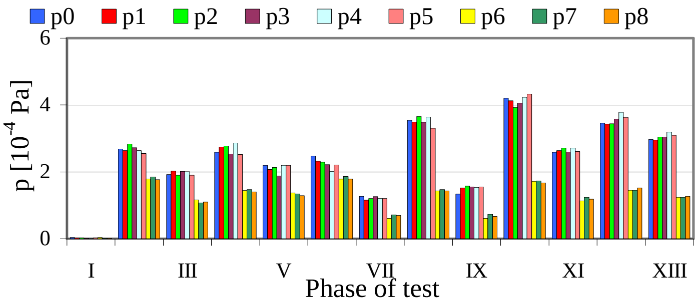

Fig. 5. Distribution of pressure in measurement point p0-p8 exhaust pipe of testing engine without catalytically converter during realization esc test [6]

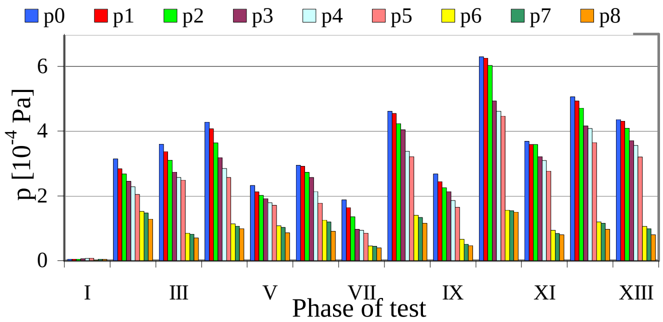

Fig. 6. Distribution of temperature in measurement point T0-T8 exhaust pipe of testing engine with 200 cpsi catalytically converter during realization ESC test [6]

In case of the catalyst the highest overpressure values were recorded for the phase x at the point p0 and they were of $6{,}3\cdot10^{-4}$ pa for the catalyst equipped with the 200 cpsi carrier.

5. CONCLUSIONS

On the basis of the performed examinations and obtained test results the following conclusions can be drawn:

1. The analysis of the NO_x concentrations in exhaust gas from the compression-ignition engine can be based on the indications of the voltage probes with the modified electrodes of the oxygen pump.
2. The application of the reduction conditions in the voltage probes using the nitrogen oxides reduction by the electro-catalytic way depends on the exhaust gas parameters, the values of which change depending on the rotational crankshaft

speed and engine load. For this reason obtaining the diagnostic signal for the whole engine operation range is impossible. The control of the correctness of the catalyst operation regarding the nitrogen oxides reduction can be realised for the defined operating parameters of the tested engine.

3. For phases VIII and X of the ESC test the reheating the test probe installed before the catalyst was unnecessary owing to the high exhaust gas temperature (737–759^{o}C).

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ABBREVIATIONS

DeNOx	Decrease NO_x
ESC	European Stationary Cycle
NOx	nitrogen oxides
OBD II	On-Board Diagnostics II